International Journal of Recent Engineering Research and Development (IJRERD)
Volume No. 02 – Issue No. 04, ISSN: 2455-8761
www.ijrerd.com, PP. 01-12

Power characteristics and efficiency of a solar panel used for water pumping in Asmara, Eritrea.

Kamau J.N*[1] and Berhane N.[2]
*[*1] Jomo Kenyatta University of Agriculture and Technology. P.O BOX 62000-00200 Nairobi, Kenya.*
[2] Eritrea Institute of Technology, Asmara, Eritrea

Abstract: The production of sustainable, affordable and efficient power systems has been a big challenge for many countries, especially developing countries like Eritrea. A solar energy system clearly makes environmental sense by producing renewable energy and pollution free environment. Photovoltaic (PV) technology is one of the techniques of converting solar energy into other useful forms of energy. This system uses photovoltaic cells to directly convert incoming solar radiation into useful electricity. Sets of photovoltaic cells are interconnected to form a solar module and the complete set of modules (or panels) form a power-generating unit called a PV array. Photovoltaic (PV) technology has, in recent years, become a significant form of power generation in many electricity networks.This study was aimed to evaluate the performance and efficiency of an operational solar panel for water pumping. The study took place at the Ministry of Energy and Mines (Department of Energy), Asmara, Eritrea. The solar irradiance, the load voltage and current were measured and the IV and PV curves plotted. Analysis was done on the collected data, using IV curves, PV curves and the solar cells efficiency formula. It was found that the efficiency of the solar module, Conergy P175M type, was 11.4%, which is within the range of the expected efficiency. Cooling and cleaning the panels were found to increase the overall efficiency.

Key words: Solar cells, irradiance, PV technology, efficiency, fill factor

Introduction

There are various types of renewable energy resources. Many of them have limitations, including hydropower, wind energy, and geothermal energy. Solar photovoltaic technology is the single most promising substitute for fossil energy (Chen, 2011). Over the past several decades, PV manufacturing costs and sales prices have dropped dramatically while experience accumulated by solar manufacturers and developers, utilities, and regulatory bodies has shortened the time and expense required to install a fully operating PV system(US department of Energy, 2012). For many years the most common use for solar panels was to provide electric power for satellites. Currently solar panels provide energy to private residences, businesses and cities with large scale demands. Large scale power conversion solar cells have many problems, though. The most serious of these is the wide variation of voltage and current, which oscillate directly with the amount of sunlight. This can be compensated by storing the energy produced during peak periods in batteries. Another solution to this problem is to create a grid tied system, which outputs the energy not being used directly back into the grid. The energy transferred back into the grid can be metered and private companies or residences can sell it to the local utilities. However, this still does not solve the problem of energy storage when too much energy is produced (Butler *et al*, 2006).

In general, there are three common types of solar systems; off-grid solar system, grid tied solar system and a hybrid solar system. An off-grid system uses a bank of batteries to store excess energy for use when needed. A grid-tied system is used to sell excess energy back to the electric grid for credit and a hybrid system is grid-tied with battery backup. The hybrid system is meant to be self-sustaining but if needed, can draw extra power from the electric grid or sell power back.

The basic components that make up a hybrid solar system are; the solar panels, batteries, charge controllers and inverters. The solar panels charge the batteries while in sunlight. The charge controller determines how much power the batteries need to reach full charge or controls the batteries are not over charged or they are not drained too much. The inverter converts the direct current from the batteries to an alternating current for use in the residence and also determines when to switch from battery to grid power (Alouani, 2008).
One of the countries which are striving to harness this natural gift of solar energy is Eritrea. It is a horn African country along the coast of the Red Sea located between latitudes 12° 42' N to 18° 2' N and longitudes 36° 30' E to 43° 20' E (Beraki, 2005). The capital city of Eritrea is Asmara located at about 15.28^0N and 38.92^0E, at an altitude of 2325 m above sea level (Solar Energy Laboratory, 2006).The study was carried out at the Ministry of Energy and Mines, department of Energy, Villago located at $15^0 21.48'$N latitude and $38^0 53.46'$E longitude, 2230m above sea level (Kibret, 2006).

In Eritrea, different assessment works had been conducted by deploying 25 metrological stations in three geographical regions of the country namely; the eastern lowland, the Central highland and the western lowland (Tesfay, 2007). The results found from the solar irradiance measuring devices from these stations show that the country has good solar energy potential. The data collected, according to the Ministry of Energy and Mines, shows that Eritrea has daily mean solar irradiances, in most places, of around 6.5kWh/m^2/day which is among the best solar resources in the world (Kibret, 2006).

Metrological data collected from 2000-2005 by the Ministry of Energy and Mines also deduces that, the average daily solar irradiance recorded in Asmara reaches about 6.0155 kW/m^2/day (average of the six years in consideration) fluctuating from 4.725 kW/m^2/day (in July, 2005) up to 7.909 kW/m^2/day (in May, 2004), which demonstrates a good potential for solar power system plantations such as photovoltaic technologies in the country (Kibret,2006).

Efficiency of solar cells

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of output power from the solar cell to input power from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25°C at an irradiance of 1000W/m^2. Solar cells intended for space use are measured under AM0 conditions.
The efficiency (η) of a solar cell is determined as the fraction of incident power which is converted to electricity and is given as

$$\text{Efficiency} = \frac{\text{Voc Isc FF}}{\text{Pin}} \quad \ldots\ldots (1)$$

In which,

$$P_{max} = V_{oc} I_{sc} FF \quad \ldots\ldots (2)$$

$$P_{max} = I_{mp} V_{mp} \quad \ldots\ldots (3)$$

$$P_{in} = GA \quad \ldots\ldots (4)$$

$$P_{ideal} = V_{oc} I_{sc} \quad \ldots\ldots (5)$$

$$Irradiance(\mathrm{G}) = \frac{emf\ \ output}{Sensitivity\ \ of\ the\ Pyranometer} \quad \ldots\ldots (6)$$

Where G is Solar irradiance (W/m^2), A is the Surface area of the solar module exposed to insolation, $I_{mp,}$ The maximum (peak) load current, $V_{mp,}$ The maximum load voltage, P_{max}, Maximum useful power, P_{in}, Input power as irradiance, FF is Fill factor,
Voc, the open-circuit voltage, I_{sc}, the short-circuit current (Chen, 2011).
It should be noted that the short-circuit current and the open-circuit voltage are the maximum current and voltage from a solar cell, respectively. However, at both of these operating points, the power from the solar cell is zero. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}.

Methodology

In this study, Conergy P175M type solar modules installed in the ministry of energy and mines in Villago, Asmara, Eritrea were studied. These are of monocrystalline type solar panels with maximum power yield of 175W at STC with specifications shown on Table 1. Pyranometers, multimeters, variable resistor (rheostat) and other accessories, as required, were used to measure solar irradiance, voltage, current, resistance, and used to calculate the efficiency of the solar panels from the collected data.

Table 1: Specifications of Conergy P 175 M solar module

Maximum Power(P_{mpp})	175 W
Output Tolerance	+/- 3 %
Rated Voltage(V_{mpp})	36.0 V
Rated Current(I_{mpp})	4.86 A
Open Circuit Voltage(V_{oc})	44.8 V
Short Circuit Current (I_{sc})	5.17 A
Maximum System Voltage	748 V

The 7 modules (shown in Figure 1) were driving an electric motor for pumping water from an underground well for the ministry of energy and mines, and to a nearby hospital. Out of these solar modules of the same type, two modules were chosen for the data collection which enabled a good comparison in case simultaneous measurements involving two different conditions of the modules, such as one with a clean surface and the other dusty, one normal and the other cooled with water.

Figure 1: PV array (Conergy P175 M), at the Ministry of Energy and Mines, Villago.

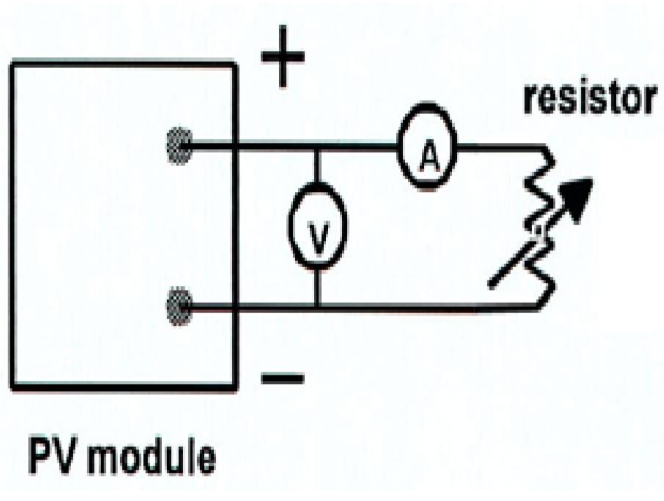
Within each of the solar modules, 72 Monocrystalline solar cells were connected in series, and were designed to yield a maximum useful voltage of 36.0V and 4.86A of useful current, producing a maximum power of 175watts under a load at STC. The modules had an open circuit voltage of 44.8V and a short circuit current of 5.17A.

The actual dimensions of the solar module are given as follows: Length (L) = 1,580mm, Width (W) =808mm and Thickness (d) =40 mm.

For the practical calculation of the efficiency, the 1cm edge surrounding the module was deducted from the actual dimension. Therefore, the effective surface area receiving the solar radiation was left as $A=1.25m^2$.

The solar modules were installed at an angle of about 9 degrees with respect to the horizontal surface of the earth which faced towards geographic south as is recommended for countries in the Northern hemisphere like Eritrea. The solar irradiance was measured using a Pyranometer (Kipp and Zonen) with sensitivity of $9.94x10^{-6}V/W/m^2$.

Figure 2(a) shows the electric circuit followed during the experimental measurement, comprising the solar module, an ammeter, a voltmeter and a variable resistor and Figure 2(b) shows the actual circuit connections on site.



a.

b.

Figure 2 (a) The experimental electric circuit diagram under load (b) the corresponding circuit image

The data was collected every 15 minutes for 8 days, typically from 9:00 am up to 4:00 pm. The Microsoft Excel software was used to plot the results of the experiments into a graph and different characteristic curves. The ideal power output, maximum useful power output, Fill Factor (FF), the incident power radiation- as a result of all these -the efficiency was calculated using the formulae given in equations (1), (2), (3), (4) and (5).

Results, Analysis and Discussion

The solar irradiance distribution over a day in the site in relation to the outputs of the module was one of the basic tasks of the experiment. Note that ideal power is the product of the open circuit voltage and short circuit current. Figure 3 shows the variation of ideal power with different times of the day; from 9.15 am to 5.15 pm.

From the graph in figure 3, it can be shown that the maximum power from solar radiation can be attained around noon. In the morning, the solar irradiance starts with a low intensity and reaches its maximum at the midday. After noon, the irradiance starts to decrease and eventually goes to zero almost after 5.15 pm. This process is symmetrical on both sides from the noon, but the trend in the irradiance may be altered by the cloud cover, humidity, shades and anything that obscures the sun`s radiation. The solar modules maximum power point and efficiency are greatly driven with these changes of irradiance in addition to their intrinsic performance nature.

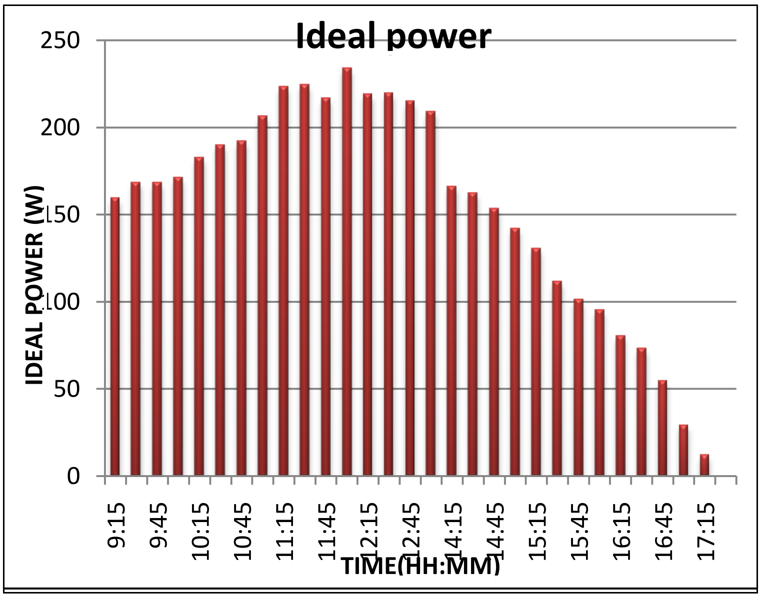


Figure 3: The Ideal power versus time within a day

Table 2 shows a data collected for the V_{oc}, I_{sc}, V_{max} and I_{max} for a typical day from the module at different irradiances which helped at calculating FF, P_{max} and efficiency of the solar module.

Table 2: I, V, and P data of the solar module conergyP175M type at different conditions

G=996W/m^2 T$_a$=27^{o}C , Tmodule=47 ^{o}C 12:44pm			**G=851W/m^2 T$_a$=25^{o}C Tmodule=42 ^{o}C 1:37 pm**			**G=643W/m^2 T$_a$=23^{o}C Tmodule=36 ^{o}C 2:54 pm**			**G=488W/m^2 T$_a$=23^{o}C, Tmodule=30 ^{o}C 3:32 pm**		
V	I	P	V	I	P	V	I	P	V	I	P
0	5.43	0	0	4.88	0	0	3.43	0	0	2.68	0
2.1	5.44	11.42	2.5	4.82	12.1	1.6	3.4	5.44	1.4	2.66	3.72
11.6	5.36	62.18	2.7	4.8	13	3.3	3.43	11.3	1.5	2.67	4
21.9	5.15	112.8	6.3	4.76	30	6.5	3.41	22.1	5.1	2.66	13.5
25.2	5.07	127.7	11	4.76	52.4	11.5	3.39	39	15	2.64	39.6
29.4	4.81	141.5	27	4.65	127	15.2	3.39	51.5	21.1	2.63	55.4
31.6	4.29	135.6	28	4.61	131	18.6	3.39	63.1	27.3	2.62	71.6
32.6	3.95	128.8	30	4.44	133	20.1	3.4	68.3	28.6	2.61	74.7
33.9	3.56	120.6	31	4.29	133	24	3.39	81.4	30.1	2.58	77.6
35.2	2.91	102.4	32	4.1	131	27.6	3.36	92.7	30.2	2.58	77.9
36.3	2.27	82.22	32	4.1	131	31	3.23	100	31.7	2.53	80.3
37	1.86	68.82	33	3.96	129	34.3	2.77	95	32.3	2.48	80.1
37.4	1.61	60.14	34	3.51	119	35.4	2.51	88.7	34.5	2.32	80.1
37.5	1.51	56.55	35	2.98	104	37	1.98	73.3	35.3	2.18	77
37.7	1.38	52.1	35	2.93	104	37.3	1.75	65.4	37.1	1.77	65.7
37.9	1.21	46.01	36	2.4	87	37.9	1.49	56.5	37.5	1.61	60.5
38.0	1.05	39.9	38	1.44	54.4	38.4	1.19	45.8	38.1	1.43	54.3
38.1	0.84	32.12	38	1.26	48.1	38.6	1.07	41.1	38.4	1.27	48.6
38.1	0.9	34.21	38	1.05	40.3	38.9	0.88	34.2	38.8	1.09	42.4
38.2	0.77	29.41	39	0.96	37	39.1	0.7	27.4	39	1.01	39.3
38.2	0.78	29.95	39	0.84	32.6	39.3	0.6	23.5	39.2	0.91	35.7
38.3	0.7	26.85	39	0.7	27	39.4	0.54	21.4	39.4	0.8	31.5
38.4	0.48	18.36	39	0.72	27.9	39.5	0.49	19.4	39.6	0.72	28.3
38.45	0.58	22.15	39	0.58	22.5	39.5	0.46	18.1	39.8	0.62	24.6
38.5	0.44	16.75	39	0.51	20	39.5	0.43	16.8	40	0.55	22
38.6	0.38	14.82	39	0.5	19.4	39.5	0.38	15.1	40.1	0.49	19.8
38.6	0.39	14.98	39	0.46	17.8	39.5	0.36	14.3	40.2	0.43	17.3
38.6	0.44	16.83	39	0.4	15.5	39.6	0.41	16.2	40.3	0.38	15.3
39.2	0	0	39	0.36	14.1	39.6	0.33	13.1	40.4	0.34	13.8
39.3	0	0	40	0	0	39.8	0	0	40.8	0	0

The IV curves shown in figure 4 represent current versus voltage characteristics of the solar module at different solar irradiances within a day. The IV curves trend clearly dictates that the curves grow bigger and bigger with the increase in irradiance falling on the surface of the module. As such, the maximum power output of the module increases as far as the maximum current and voltage increase with irradiance as shown in figure 5. The maximum power from the solar cell is obtained when the resistance of the load is selected such that it allows both the current and voltage to be maximized. This particular point where we have maximum power for a particular irradiance is called the maximum power point, $P_{max,}$ where $\mathbf{P}_{max}=I_{mp}V_{mp}$

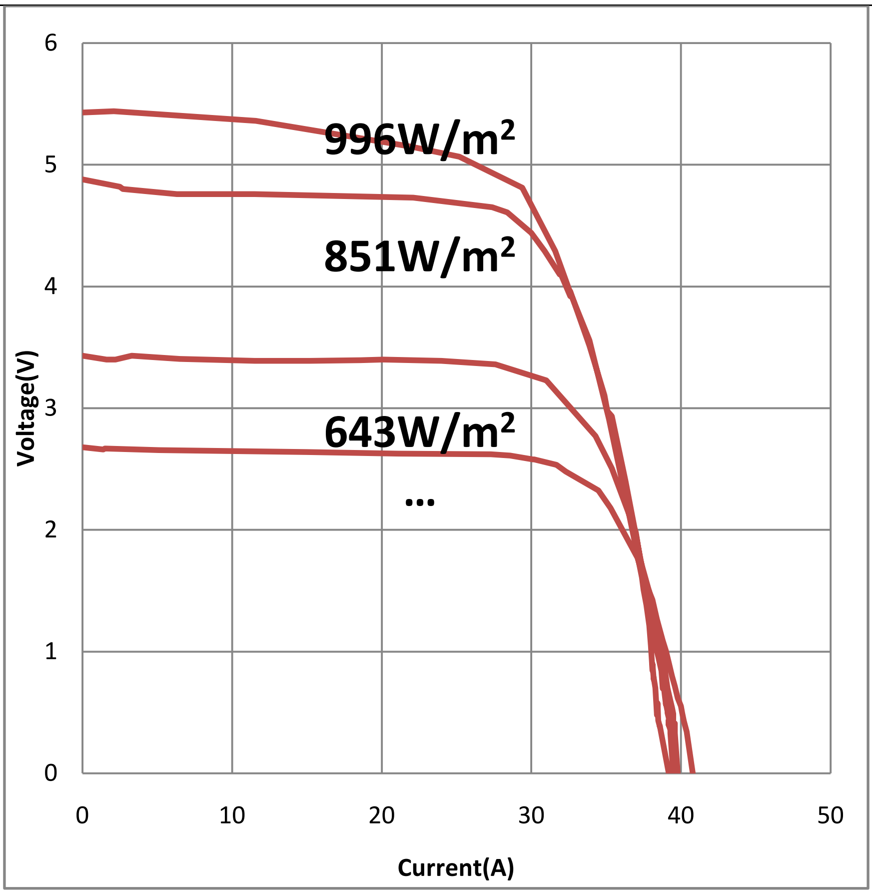


Figure 4: Characteristic IV curves at different irradiances

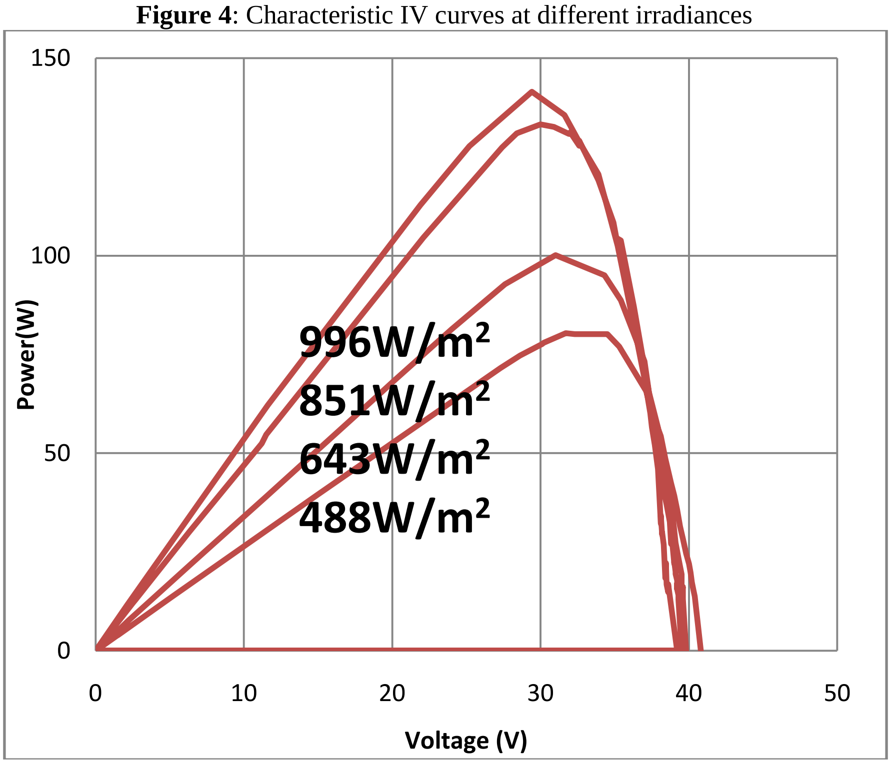


Figure 5: Characteristic PV curves at different irradiance

Experimental results showed that, with the change of temperature, the most significantly changing parameter of the module is the voltage. According to Tobnaghi *et al,* 2013, reduction in the open-circuit voltage for silicon solar cells is about 2mV/°C.

For the specific case of Conergy P175M solar module the temperature coefficient (V_{OC}) was -*0.148V/°C* (www.kogybox.com). Notice that if 0.148V/° C is divided for 72 cells of the module, it gives about 2.06mV/° C which agrees with Tabnaghi *et al* .,2013 report. This implies, for every degree Celsius of temperature increase the open circuit voltage of the module decreases by 0.148V.

For example, at G= 996W/m^2, T_{module} = 47^{0}C and $T_{ambient}$=27^{0}C $V_{oc,\ at\ 47\ ^0C}$=39.3V

$V_{oc,\ reduction}$= (0.148V/^{0}C) x (47^{0}C -25^{0}C) = 3.256V, $V_{oc,\ reduction}$=3.26V

If the temperature of the module could be maintained at 25^{0}C,

$V_{oc,\ at\ 25\ ^0C}$ =39.3+3.26=42.56V , **$V_{oc,\ at\ 25\ ^0C}$=42.56V** at G=996W/m^2

At G=488W/m^2, T_{module} = 30^{0}C and $T_{ambient}$=23^{0}C , $V_{oc,\ at\ 30\ ^0C}$=40.8V

$V_{oc,\ reduction}$= (0.148V/^{0}C) x (30^{0}C -25^{0}C) = 0.74V, $V_{oc,\ reduction}$=0.74V

If the temperature of the module could be maintained at 25^{0}C,

$V_{oc,\ at\ 25\ ^0C}$ =40.8+0.74=41.54V **$V_{oc,\ at\ 25\ ^0C}$=41.54V** at G=488W/m^2

From the above analysis,

$V_{oc,\ at\ 25\ ^0C}$=42.56V at G=996W/m^2 is larger than the $V_{oc,\ at\ 25\ ^0C}$=41.54V at G=488W/m^2

The above analysis shows that the IV and PV curves for G=996W/m^2 would totally dominate the IV and PV curves for G=488W/m^2 and there would be no any crossovers or intercepts between two different curves, which agrees with the theoretical analysis.

The efficiency of the solar module was calculated for different irradiance values from the available data and using equation 1. The results are shown in table 3.

Table 3: Efficiency results for the selected data

	Time(HH:MM)	G(W/m^2)	Pmax(W)	FF	Efficiency (%)
A	12:44	996	141.5	0.66	11.4
B	13:37	851	132.6	0.69	12.5
C	14:54	643	100.1	0.73	12.5
D	15:32	488	80.1	0.74	13.2

It is clear from the table 3 the efficiency seems to increase with the decrease in solar irradiance. Figure 6 shows the variation of efficiency with irradiance.

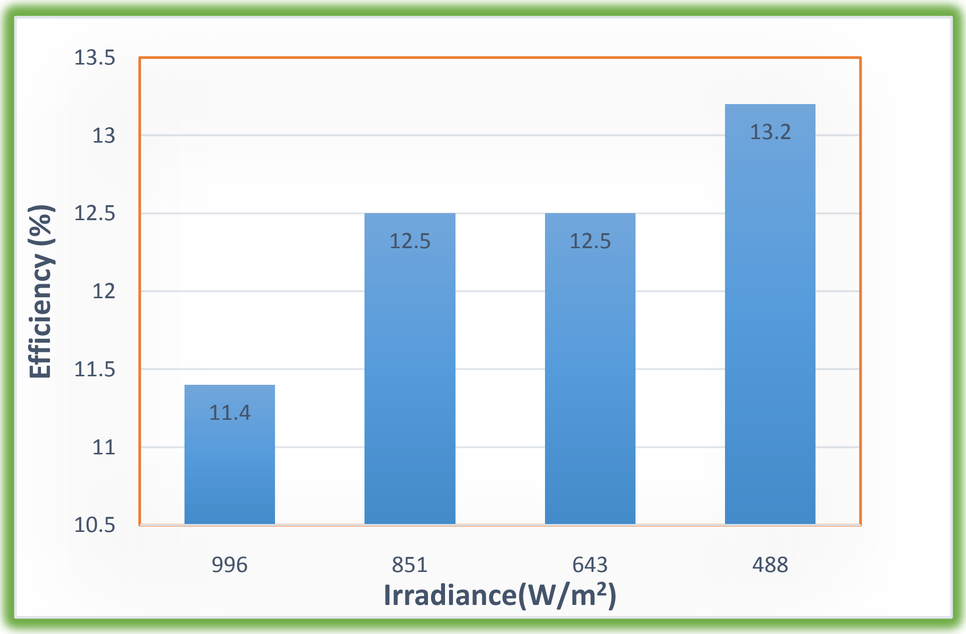


Figure 6: Variation of efficiency with irradiance

Apart from the basic parameters that give rise to the efficiency calculations, the solar module`s efficiency is greatly influenced by the temperature change within the module as it is the function of the parameters which are the primary candidates of the impact. The more the temperature, the less becomes the efficiency of the modules, because the denominator in the efficiency formula in equation 1 (total power input) is not affected by the temperature change within the module, whereas the numerator (maximum useful power output) in the equation is greatly influenced by the temperature change. In our case, for the conergy P 175M module type, the maximum power output is decreased by an amount of 0.44% for every increase in degree Celsius in temperature (www.kogybox.com). From the results found, it should be clear that larger maximum power production from a module does not necessarily mean a higher efficiency. Compared to the manufacturers claim for the solar module, which was 13.7% at STC, the experimental result which corresponded to 11.4%.

A measurement of the effect of dusts on solar panels was also conducted. Two modules of the same type (Conergy P175M), one clean and the other dusty, were taken under consideration in which all measurements were done simultaneously on both modules for the same solar irradiance falling on them. The degree of dustiness on the module`s surface can be roughly imagined as if the module was not cleaned for a month of normal days. The experimental data for this effect has been presented in table 4.

Table 4: Clean and dusty modules parameters measurement data

Clean module Ta=23^0C Time 14:25 G=705W/m^2			Dusty module Ta=23^oC Time 14:25 G=705W/m^2		
V	P	I	V	P	I
0	0	3.93	0	0	3.74
1.7	6.759	3.98	1.5	5.7	3.8
2.3	9.131	3.97	3.5	13.3	3.8
8.4	33.18	3.95	4.8	18.2	3.79
21.4	83.89	3.92	12.5	47	3.76
28	107.8	3.85	15.8	58.9	3.73
30.1	112.6	3.74	22.5	83	3.69
32.8	107.3	3.27	27.2	99.6	3.66
33.6	101.1	3.01	32	107	3.35
35	88.2	2.52	33	106	3.2
36.5	70.63	1.94	33.7	102	3.02
37.3	56.7	1.52	35.4	87.8	2.48
37.6	56.4	1.5	36.6	72.5	1.98
37.8	46.49	1.23	36.8	68.4	1.86
38.2	42.63	1.12	37.4	58.7	1.57
38.3	33.7	0.88	37.8	50.7	1.34
38.4	32.49	0.85	38.1	44.8	1.18
38.6	27.17	0.7	38.2	41.6	1.09
38.8	23.28	0.6	38.3	38.7	1.01
39	20.2	0.52	38.6	33.4	0.86
39	18.14	0.47	38.7	30.3	0.78
39.3	16.23	0.41	38.8	27	0.7
39.4	13.99	0.36	38.9	24.5	0.63
39.5	0	0	39	21.7	0.56

The maximum power generated from the clean module dominates the output power of dusty module. This clearly implies that the accumulation of dusts on the surface of solar modules reduces the maximum power point output and the efficiency of the given module as expected.

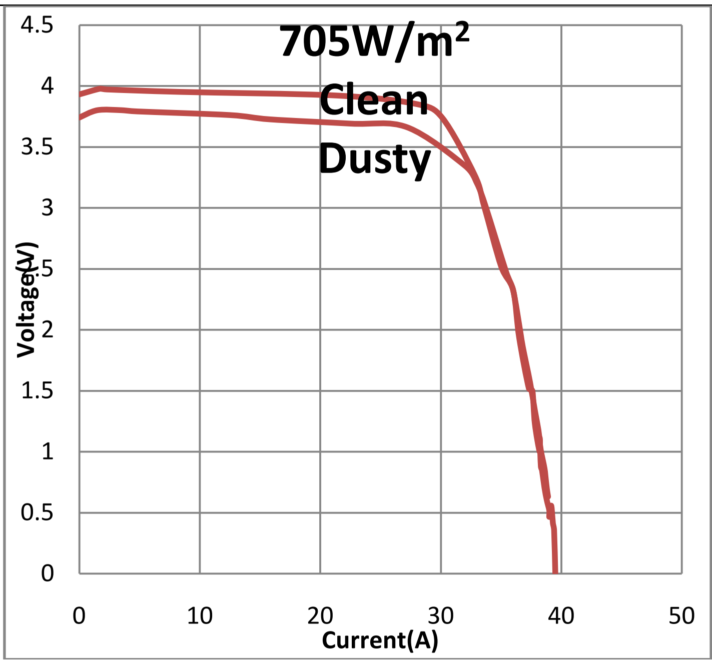


Figure 7: IV curves of a clean and dusty module at the same irradiance (G=705W/m^2)

The maximum power point for the dusty module was found to have decreased from 112.6W to 107.0W in comparison with the clean module. This was about 5% reduction in power production.

The efficiency of the dusty module was also found to have reduced from 12.8% to 12.1% in comparison to the clean module. This efficiency reduction is about 5.5% due to the dust on the surface of the module.

Generally, the main reason for this reduction effect is the resistance of the dusty particles for the irradiance, which reduces the fraction of radiation reaching the solar cells within the module. It was discussed previously that the reduction in irradiance specially affects the output current than the output voltage. This experimental result is in agreement with the theory. In the IV curve shown in figure 7, the accumulation of the dust reduces the current more that it does for the voltage, reducing the overall performance of the module. It is advised that solar modules have to be cleaned regularly to enhance their performance. The corresponding PV curves for the clean and dusty modules are shown in figure 8.

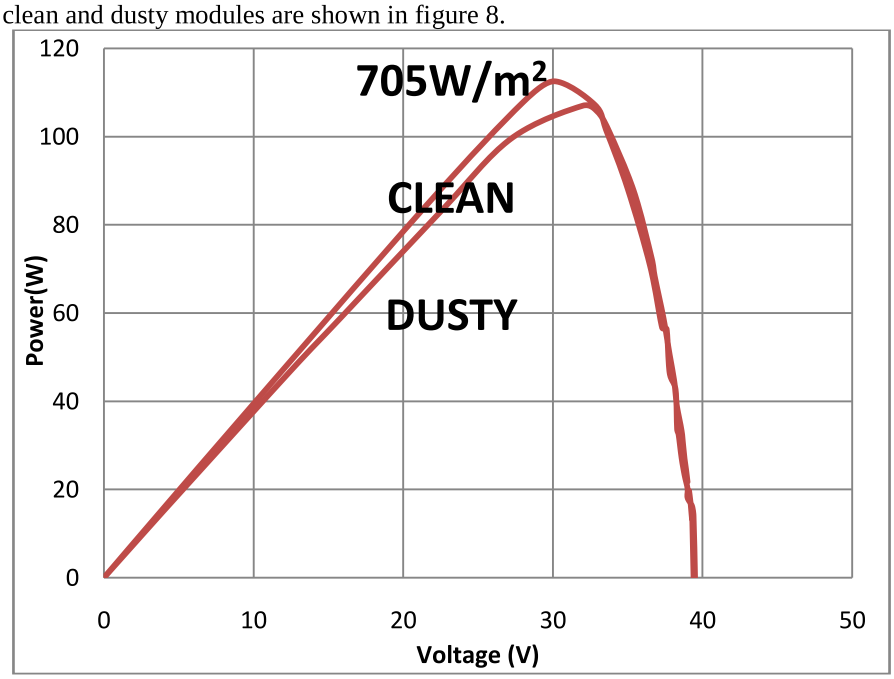


Figure 8: PV curves for the clean and dusty modules at G=705W/m^2, Time 14:25, Ta=23^{0}C

The effect of cooling plays a significant role in solar modules maximum power point output and efficiency. In the study, two modules were considered, out of which one is cooled with water flushed on its surface and the other operating normally. The experiment took place simultaneously at the same irradiance of 643W/m^2 and an ambient temperature of 23^{o}C. The result that was found was consistent with the theoretical concepts of cooling solar cells or modules. The module`s potential difference was found to increase after water was flushed on its surface. The experimental data on the effect of cooling in solar modules is given in table 5.

Table 5: Data collected on effect of temperature in solar modules

Normal module Ta=23 ^{0}C G=643W/m^2			Cooled module Ta=23 ^{0}C G=643W/m^2		
V	P	I	V	P	I
0	0	3.43	1.6	5.48	3.428
1.6	5.44	3.4	2.1	7.2	3.43
2.2	7.58	3.44	4.7	16.1	3.42
3.3	11.3	3.43	8.3	28.2	3.4
6.5	22.1	3.40	12.7	43.1	3.39
11.5	39	3.39	17	57.5	3.384
15.2	51.5	3.39	21.3	71.9	3.38
18.6	63.1	3.39	23.6	79.4	3.36
20.1	68.3	3.4	28.7	95.9	3.34
24	81.4	3.39	31.9	104	3.27
27.6	92.7	3.36	34.3	107	3.12
31	100	3.23	36.1	103	2.86
34.3	95	2.77	37.3	96.2	2.58
35.4	88.7	2.51	38.3	88.4	2.31
37	73.3	1.98	39.1	77.8	1.99
37.3	65.4	1.75	39.8	71	1.79
37.9	56.5	1.49	39.9	68.6	1.72
38.4	45.8	1.19	40.2	63.8	1.59
38.6	41.1	1.066	40.5	59.9	1.48
38.9	34.2	0.88	40.7	54.1	1.33
39.1	27.4	0.7	41	48.7	1.19
39.3	23.5	0.60	41.3	43.7	1.06
39.4	21.4	0.54	41.5	37.4	0.90
39.5	19.4	0.49	41.7	35.2	0.843
39.5	18.1	0.457	41.8	30.8	0.737
39.5	16.8	0.43	41.9	28.5	0.68
39.6	16.2	0.41	42	22.8	0.544
39.5	15.1	0.39	42.1	22.1	0.525
39.5	14.3	0.36	42.2	18.1	0.43
39.6	13.1	0.33	42.3	16.8	0.40
39.8	0	0	42.8	0	0

The IV and PV curves corresponding to the above table 5 are plotted in figure 9 and 10 respectively. It is clearly shown from the characteristic curves of the module that the effect of cooling a solar module increases the performance of the system. From figure 10, it can be deduced that the voltage output of the module increases if the temperature of the module is maintained at a lower temperature, which agrees with the theoretical IV curves. Cooling effect has a negligible impact on current output in comparison to the voltage output. Is has to be noticed, though, that cleaning modules from accumulated dust particles does the opposite; it increases the current output and leaves the voltage almost unchanged.

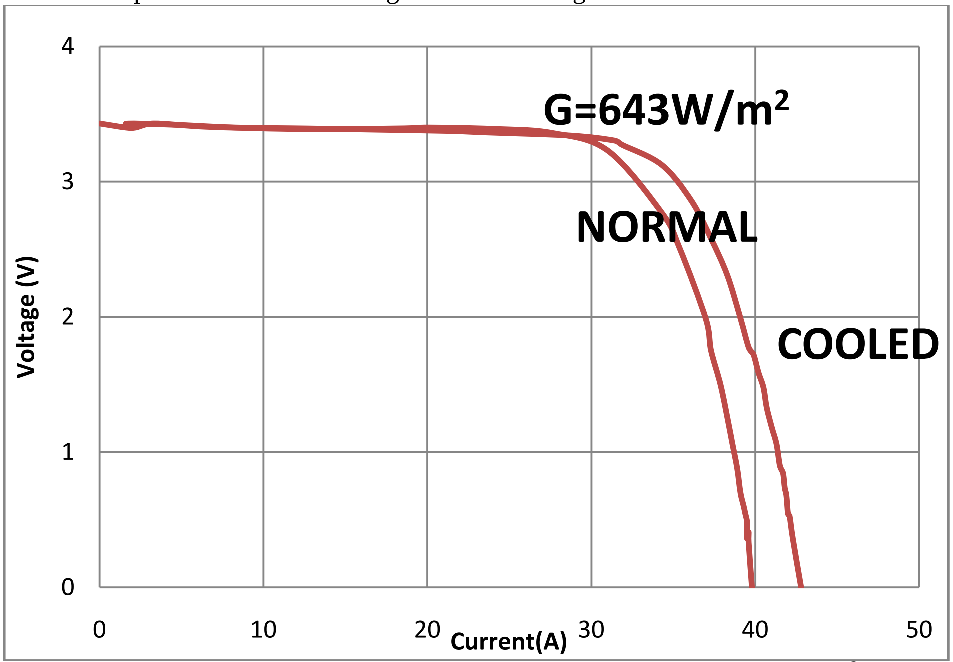


Figure 9: IV curves for normal and cooled PV modules at G=643W/m^2

The maximum power point increased from 100.1W to 107.2W when cooled. This indicates a 6.6% of maximum operating power increase when the module is normally flushed with water on its surface.

The efficiency increased from 12.5% to 13.3% when the module is cooled. This implies a 6% increase in efficiency when the module is cooled. From this result, it can be concluded that, cooling a solar module has a positive impact on the performance of the system. The PV curves in figure 9 illustrate this effect.

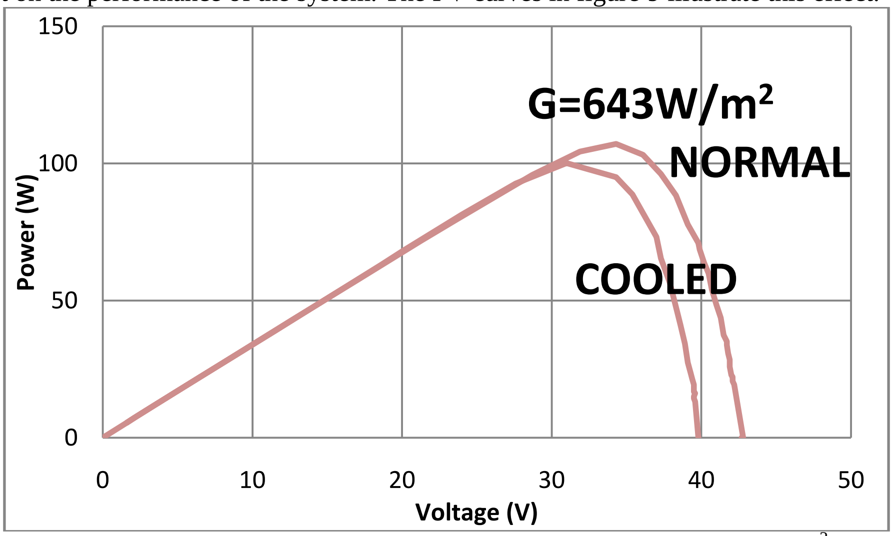


Figure 10: PV curves for the clean and cooled modules at G=643W/m^2

Conclusion

The experimental result showed power increase from 9.15 am to peak at noon before reducing gradually to almost zero at 5.15 pm. An efficiency of 11.4 % compared to the manufacturers claimed efficiency of13.7 % was observed. Dust contributed an efficiency reduction of 5.5% while cooling increased maximum power from 100.1 W to 107.2 W, an efficiency increase of about 6 %.

Acknowledgements

The authors would like to thank JICA, JKUAT and EIT for the sponsorship. The authors are also grateful to Prof. Mihreteab Tsegay and Mr. Yosief Kassahun, both of EIT and Mr. Tesfay of Department of Renewable Energy for their assistance during the course of the study

REFERENCES

[1]. Alouani A. T. (2008). *Enota Solar Design Project*. Tennessee Technological University Cookeville, TN 38505.
[2]. Beraki A. F. (2005) Climate Change Scenario Simulations over Eritrea by Using a Fine Resolution Limited Area Climate Model: Temperature and Moisture Sensitivity. *M.Sc. thesis in natural and agricultural sciences*, University of Pretoria. South Africa.
[3]. Butler K., Theesfeld S., Nahm A., Mike B.G. and Struck S.K. (2006). *Solar Energy Power in the city of Boulder, Colorado* .GEOL 4080 Hartmut Spetzler
[4]. Chen C. J. *Physics of Solar Energy*. (2011).Columbia University. John Wiley & Sons, Inc. Hoboken, New Jersey.
[5]. Kibret S. (2006). *Wind and Solar Monitoring Network (WSMN), Summary report.* Ministry of Energy and Mines, Department of Energy. Asmara, Eritrea.
[6]. Jha A.R. (2010). *Solar Cell Technology and Applications. AUERBACH PUBLICATIONS, CRC press. New York, USA.*
[7]. Lombardi V. (2012). *A practical guide to Solar Power System Design for Homeowners*. Virginia Tech 1988/1990, Version 08.08.12
[8]. Ministry of Land, Water and Environment. (2001). *Ministry of Land, Water and Environment*. Asmara, Eritrea.
[9]. Patel M. R. (1999). *Wind and Solar Power Systems*, CRC press LLC, New York, USA.
[10]. Samuel B., (2000). *Investment Opportunities in the Energy Sector of Eritrea*. Ministry of Energy and Mines. Asmara, Eritrea.
[11]. Solar Energy Laboratory, (2006). *Transient System Simulation program weather data.* University of Wisconsin-Madison. *TRNSYS 16*, **9**
[12]. Tesfay Z. (2007).*Renewable Energy Resources in Eritrea.* . Ministry of Energy and Mining.
[13]. Tobnaghi D. M., Madatov R., and Naderi D. (2013). The Effect of Temperature on Electrical
[14]. Parameters of Solar Cells. *International Journal of Advanced Research in Electrical,*
[15]. *Electronics and Instrumentation Engineering.* **2**, (12**).**
[16]. UNDP Energy hand book, (2007). UNDP
[17]. US department of Energy. (2012). *SunShot Vision Study* Pp. 69.
[18]. https://en.wikipedia.org/wiki/Shockley%E2%80%93Queisser_limit , retrieved on 01/12/2015, 21:31
[19]. http://www.kogybox.com/uploads/assets/kogybox/fiches_pdf/Fiche_technique_TD_Conergy_P_170-190MEN , retrieved on 15/11/2015 , 16:40
[20]. www.thegreenage.co.uk/tech/types-of-solar-panel/ , retrieved on 16/10/2015, 11:40
[21]. www.wholesalesolar.com , retrieved on 19/10/2015, 14:17